

PHOSPHORUS BUDGET, CYCLE, AND FACTORS AFFECTING REDISTRIBUTION IN THE ENVIRONMENT

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The contemporary problem of phosphorus in the aquatic environment represents a somewhat frustrating situation for soil science. This is particularly true in view of the long standing concern of many soil scientists regarding erosion losses and the accompanying loss of plant nutrients.

Except for limited acreages of soils derived from basalt, phosphorus deficiency is a characteristic, in some degree, for most soils in the world. This situation, combined with the average phosphorus content of the lithosphere, could lead to some conjecture that dispersion of phosphorus in the environment has had a long history. It may well be that the continuing emphasis on the immobility of phosphorus in the soil, based on the knowledge of soil chemistry, has been slightly overdrawn in presenting the full picture of a phosphorus cycle or cycles.

Wadleigh and Britt (67) suggest that northern Minnesota is a monument to eutrophication which preceded any major effect of man's activity. Studies in Minnesota indicate 6.8 billion tons of peat in the state averaging over 1.5 per cent nitrogen or more than 100 million tons of nitrogen. We could estimate phosphorus contents of at least 0.1 to 0.2 per cent or some 7 to 8 million tons. Much of this current nutrient supply would have occurred in an aquatic environment. It must be recognized, of course, that the contemporary connotation of eutrophication in water is somewhat different to the original application to organic soil accumulation.

There can be no argument with the effect of urbanization, domestic and industrial use of phosphates as detergents and water conditioners, and intensive livestock operations on the levels of phosphorus, other nutrient elements, and growth factors or inhibitors in water. The picture in regard to agricultural land and any simple correlation between use of phosphate fertilizer and losses to a water system is not so clear. There is good reason as well to insist on indicated major phosphorus additions to water, well before the impact of man's much criticized remaking of the environment.

Historical

Bird (9) includes a number of interesting quotations from explorers and others. McDonnell's journal of 1795, describing a descent of the Qu'Appelle river states "Observing a good many carcasses of buffaloes in the river, and along its banks, I was taken up the whole day with counting them, and, to my surprise, found I had numbered when we put up at night, 7,360, drowned and mired along the river and in it".

Alexander Henry described a situation near Grafton, North Dakota, in the early nineteenth century, "This afternoon I rode a few miles up Park River. The few spots of wood along it have been ravaged by buffaloes; none but the large trees are standing, the bark of which is rubbed perfectly smooth, and heaps of wool and hair lie at the foot of the trees ——. The bare ground is more trampled by these cattle than the gate of a farmyard". Again, Coues, 1897, quotes from Henry "Buffalo have destroyed all the grass and our horses are starving — Numerous paths, some of which are a foot deep in the hard turf, come from the plains to the brink of the river, and the vast quantity of dung gives this place the appearance of a cattle yard".

Henry also described the condition on the Red River for April, 1801, "It is really astonishing what numbers have perished, they formed one continuous line in the current for two days and two nights. April 18th — Drowned buffalo still floating down the river, April 25th. Drowned buffalo drift down river day and night. May 1st. The stench from the vast numbers of drowned buffalo along the river was intolerable". The buffalo were drowned apparently as they tried to cross weak ice in the spring.

It is obvious that the impact of the buffalo on water quality was significant. McDonnell's one-day count alone would represent an addition of close to 50,000 pounds of total phosphorus along with other constituents. It is, of course, impossible to provide reasonable conjecture on the fate of the phosphorus. The content of bone material in the sediments, however, may represent phosphorus which can be re-cycled, especially in shallow lakes. It is interesting to note that high phosphorus levels in certain soils and strata of southwestern Saskatchewan might be attributed to dinosaur remains as a possible source.

The extensive and recurring prairie fires represent another potential for nutrient losses from the land. Hind, 1859 (9) wrote "From beyond the south branch of the Saskatchewan to Red River all the prairies were burned last autumn, a vast conflagration extending for one thousand miles in length and several hundred in breadth". There appears to be little information in the literature on potential losses from burned prairie vegetation. One could insist, however, that fall burning would provide conditions for significant losses of nutrients through spring runoff, and ready movement by wind, as well as some smoke losses.

Studies by Beaton (5) and Smith (60) on nutrients in the soil after burning of wooded sites, show increased levels of phosphorus in ash and unburned organic matter, reasonable mobility of the phosphorus and indicated losses from the site. It would seem reasonable to conclude that the prairie fires, as well as constituting questionable management of the environment would provide conditions for nutrient mobility.

Another area of phosphorus additions to water and sediment, that must be considered is that of losses during soil formation. Simonson (58) reviewed studies which indicate, up to 90 per cent of the phosphorus present in parent rock has been lost during soil formation on ultisols. He lists mollisols as the opposite extreme, but suggests some mobility and losses even on these soils.

Data for Saskatchewan soils reported by Blackburn (10) Munro (45) Day (17) and earlier analysis by Mitchell et al (42, 43) would also suggest significant losses from gray-wooded soils, eluviated chernozems and some water-modified materials. Data for Alberta soils by Alexander and Robertson (2) show the same trend.

Soil testing data, and other extractable phosphorus studies show relatively higher extractable phosphorus on the more strongly developed soils. The changes in phosphorus content are not accounted for in the B horizons and there is a good indication of Simonson's suggested losses at the weathering front. On gray-wooded soils for example, there is a generally saturated condition of the upper part of the solum at periods of the year. Seepage from above the B horizon is obvious in road cuts. Redox conditions and impermeability of the B horizon may contribute to periods of moderate mobility of phosphorus.

Smeck and Runge (59) have recently reported on phosphorus redistribution studies in Illinois indicating losses from the landscape area. They report, however, some net gains in the more strongly developed as compared to weakly developed profiles, as compared to Simonson's thesis and reports of other workers. They report phosphorus translocations resulting in a net loss of 188.7 kg. of phosphorus from the 1.1 ha. segment of landscape.

Phosphate Budget for Saskatchewan

There have been statements implying tremendous levels of phosphate use in western Canada. The amount of phosphate fertilizer which has been used is rather trivial in relation to the removal from the land by agricultural production.

Table I shows the estimated volume of phosphorus removed by major products marketed for the 10-year period 1959-60 to 1968-69.

Table I

Estimates of Phosphorus in Products Sold in Saskatchewan
1959-60 to 1968-69

<u>Product</u>	<u>Phosphorus Contained</u> <u>'000 lbs.</u>
Grain (wheat, oats, barley, rye, flax)	586,665
Meat (cattle, calves, sheep, hogs)	43,922
Poultry	819
Milk	830
Eggs	151
Total for 10 years	632,387

The phosphorus represented by major product marketings represents well over 300,000 tons of phosphorus. The total use of fertilizer phosphorus in this 10-year period was in the order of 210,000 tons or just two-thirds of that removed from the land.

A brief look at long term wheat production in western Canada shows the tremendous volume of phosphorus removed by wheat. The wheat production for the years 1927-1968 in Manitoba, Saskatchewan and Alberta would have removed over 4,000 million pounds of phosphorus, equivalent to more than 10 million tons of mono-ammonium phosphate 11-48-0.

Only in the peak use years of 1965-66 and 1966-67 was the tonnage of 11-48-0 above that required to supply the average annual removal by the wheat crop. For much of the 42-year period from 1927 to 1967, fertilizer use was limited to little to nil. For example, use of 11-48-0 for the three provinces in 1952-53 was about 84,000 tons and represented the maximum annual use to that time. Four years later, in 1956-57 total sales of 11-48-0 for the three provinces were only 47,000 tons. To provide some indication of earlier use of phosphorus in Saskatchewan, only 238,137 tons 11-48-0 were sold in the 10-year period 1951-60. little phosphorus was represented by sales of other fertilizers, with a maximum annual tonnage of just over 2,500 tons of 16-20-0 in the 10 years.

It is interesting to note, that on a Canadian basis, the increase in urban population from 1931 to 1966 represents a concentration of an added 10 million pounds of phosphorus based on human wastes alone without any use of detergent and other phosphorus products.

Regardless of the approach, it is obvious that the use of phosphate fertilizer over the long term has been ridiculously small in comparison to the volume of phosphorus, removed, exported or concentrated by agricultural production.

There is little relevance of this budget to the economics of fertilizer use nor can it be used as a valid argument for replacement of the phosphorus removed. It is, however, quite relevant to the problems of pollution control. Crop removal over time aggravates phosphorus deficiency. Balancing the removal by a continuing modest input can very well reduce the requirements eventually needed for optimum production. There are indications that eroded land and very deficient soils require heavy application of phosphorus for satisfactory production and establishment of a vegetative cover that will control erosion. The latter situation could well represent a much more serious potential for losses to water than continuing proper application of moderate rates.

Erosion Losses of Soil and Phosphorus

It is generally agreed that the major contribution to water pollution from agricultural and other non-urban or non-industrial land is that due to erosion.

A number of estimates were made of phosphorus losses due to soil erosion, 40 years ago and earlier. A 1930 estimate (8) suggested that two million tons of phosphorus were lost annually by erosion from cropland in the U.S.A. It is interesting to note that losses from intertilled crops were estimated at 21.0 lbs. per acre, annual crops not intertilled 4.9 lbs. per acre, and, biennial and perennial crops at 10.6 lbs. per acre. It might be suggested that these estimates reflect both the effect of bare soil in the case of intertilled crops, and the probable effect of topography on biennial and perennial crops. It is worthy of note that estimated use of phosphorus at that time was 1.9 lbs. per acre (61).

Numerous reports from 1930 to the early fifties listed measurements of phosphorus losses. Scarseth and Chandler (56) concluded that 60 to 80 per cent of applied phosphorus had been lost by erosion from a loamy sand over a 26-year period. One of their interesting findings was that application of nitrogen only, resulted in removal of 618 pounds of P_2O_5 from the subsoil, 258 pounds of this removed by plants and the remainder of this subsoil plant removal, 305 pounds, lost by erosion.

Ensminger (22) reported losses, or at least, phosphorus unaccounted for, in the order of 20 to 90 per cent. The accounting approach used in these experiments is questionable as to precision and, in addition, of little value in assessing the final disposition of the phosphorus not accounted for. There was no statistical treatment of the data and experimental control was largely lacking.

Table II is a sampling of data from Ensminger's paper.

Table II

P_2O_5 Added 1930-45	lbs/acre	P_2O_5 Theoretical 0-16"	P_2O_5 Unaccounted 0-16"	P_2O_5 8-16"
Check		1256	58	575
Tri-calcium Phosphate	753	1932	317	640
Triple Super	753	1888	345	611
Superphosphate + Rock Phosphate	2296	3414	677	787

There was no sampling of the 8-16" depth at the beginning of the period in 1929 to provide any measure of variability. The data does suggest moderate to strong increases in phosphorus for the 8-16" depth and, since this was a coarse-textured soil in a humid area, it is reasonable to question the possibility of movement beyond the 16-inch depth.

There have been numerous studies carried out on the characteristics of eroded sediments. Neal (46) reported an enrichment ratio of 3.1 compared to original soil based on total phosphorus. Massey and Jackson (39) found enrichment ratios based on available phosphorus as high as 7.7, Rogers (54) reported phosphorus in eroded material only 11 per cent greater than that in original soil. Most work shows the removal of fine separates and flotation of organic material. Rogers found eroded material to contain 60 to 75 per cent of phosphorus in organic form compared to 38 to 40 per cent in original soil. In addition, organic phosphorus in eroded material showed a much higher proportion susceptible to hypobromite treatment.

It is pertinent to consider the effect of drift material, from wind erosion, on channels where it may be deposited. Moss (73) found small differences in total phosphorus between soil materials and drift materials derived from a number of soils. Nitrogen contents were much lower in drifted material from medium to coarse-textured soils. It is probable that the fine particles containing both nitrogen and phosphorus are moved greater distances in suspension and disseminated across the landscape, including water bodies.

Spratt and McCurdy (62) and Ridley and Hedlin (51) have reported on the phosphorus status of fine textured soils after long term additions of phosphorus. Table III shows some of the data reported by Spratt and McCurdy, re-calculated on a pounds per acre basis, without adjustment for bulk density. These plots would be subject to some runoff but have been well managed in a 3-year rotation. Fertilizer was applied only to the summerfallow crop.

Table III

Treatment	Total Phosphorus lbs/acre 0-6"	Increase Over Check lbs/acre
Check	1386	—
40 lbs. 11-48-0	1454	68
60 lbs. 11-48-0	1494	108
100 lbs. 11-48-0	1524	138

The results in Table III suggest that 100 per cent of the phosphorus applied over the 20-year period can be accounted for in the increased wheat yield and that remaining in the soil. It is important to note that variability, even on this reasonably uniform soil, is high. The L.S.D. for total phosphorus ($p=0.05$) is over 150 pounds per acre. This tends to indicate that precision in the accounting process would require much more experimental control, and analysis.

Spratt and McCurdy also reported data for plots receiving long term moderate additions of barnyard manure. These plots show similar to slightly higher increases in total phosphorus. The barnyard manure additions show a small but non-significant trend to lower relative proportions of organic phosphorus. Haas et al (25) have shown a similar trend for a number of sites in the Great Plains. They also show generally moderate indications of erosion losses.

The data reported by Ridley and Hedlin for clay soils at Winnipeg are similar. These plots, of course, are on very level land and one would not expect significant erosion losses.

Direct measurements of soil losses due to water erosion in western Canada are limited. Toogood (65) reported soil losses for plots at St. Albert, Alberta, for various land treatments. Plots were 72.6 feet long, located on a 10 per cent slope. The total soil lost for a 10-year period was 60 pounds per acre from virgin sod, 8400 pounds for plots in wheat after summerfallow and 18,400 pounds for the plots in fallow. Losses for the 10-year period under rotation cropping were less than 500 pounds per acre for any crop in the rotation wheat-oats-barley-hay-hay. Using a value of 0.06 per cent for total phosphorus, a conservative value for this black chernozem, the soil eroded would represent a loss of 6 pounds per acre on summerfallow, equivalent to 0.6 pounds per acre per year. Annual losses would range as low as 0.007 pounds per acre per year for sod crops in rotation and less than 0.004 pounds per acre per year on virgin sod. These results demonstrate that land use and management is probably the major fact in soil and, therefore, total phosphorus losses by runoff.

If the increase in total phosphorus, using standard rates of 40 to 60 pounds 11-48-0 per acre, as shown by Spratt and McCurdy was applied directly to the erosion losses for Toogood, one might obtain a 4 to 5 per cent increase in total phosphorus losses per year. This would, however, be balanced by greater erosion control through heavier crop growth and better residue cover on summerfallow. This reduction, as will be discussed later can be much more than sufficient to balance higher levels of soil phosphorus in eroded sediments.

The Saskatchewan Water Resources Commission (69) reports the total phosphate contributed by Moose Jaw Creek, above Moose Jaw as 390 tons PO_4 for April 6 - August 31, 1970. This amount is equivalent to about 130 tons of phosphorus. Using an average value of 0.03 per cent phosphorus for the soil in the drainage basin, gives the values for various levels of erosion loss to contribute this amount of phosphorus, Table IV.

Table IV

Depth of Soil Removed	Acres to Contribute 130 Tons Phosphorus
6 inches	433 ac.
1 inch	2600 ac.
1/10 inch	26,000 ac.
1/100 inch	260,000 ac.

Note: 1 gully 4' by 4' by 1/2 mile is equivalent

to: 2 acres 6" deep
12 acres 1" deep
120 acres 1/10" deep

Much of the soil in the Moose Jaw Creek Basin would have a native phosphorus level of 0.04 to 0.05 per cent and the acreages required to contribute the indicated phosphorus levels would be 30 to 50 per cent less than those set down in Table IV.

Phosphorus Losses from a Runoff or Drainage Chemistry Viewpoint

De Turk in 1937 (16) discussed soil conservation and chemistry. He suggested that soils of greater age in loess of Illinois showed lower phosphorus contents and that the phosphorus could have been lost to drainage waters. He listed average corn yields, unfertilized, by 12-year periods from 1888 to 1935. Yields dropped from 39.8 bushels per acre to 22.9 and acid-soluble phosphorus in the 0-20 inch depth dropped by 40 per cent. The implications for erosion are clear if such plots were on sloping land.

Kohnke in 1941 (32) urged more attention to runoff chemistry. He listed maximum concentrations of 4 to 5 pounds PO_4 per acre inch of runoff and minimums of 2 pounds per acre inch for runoff from woods, grass, meadow and corn land. Amounts appear well into the levels considered problematical for water quality from a range of land use, management and fertilizer application.

Taylor (64) has reviewed a number of aspects of phosphorus and water pollution. He lists Illinois data showing losses of phosphorus to drainage waters of 0 to 14 pounds of phosphorus per acre per year with an average of 2.5 pounds per acre per year. This is listed as "available" phosphorus and Taylor suggests that, though the amounts do appear small, one pound of phosphorus dissolved in an acre-foot of water represents a concentration of 0.3 parts per million.

Biggar and Corey (8) report data from Sylvester and Seabloom showing contents of 0.22 to 0.23 mg. soluble phosphorus per liter in subsurface drains, 0.19 to 0.20 in surface drains, under irrigation, with 70 per cent of the total phosphorus being soluble. Soluble phosphorus losses on this irrigation tract are estimated at 0.3 lbs. per acre during the irrigation season and 0.7 lbs. per acre in the non-irrigation season.

Wadleigh and Britt (67) quote results at Coshocton, Ohio showing soluble phosphorus losses of 0.03 to 0.06 pounds per acre per year, with no significant difference between a farmed watershed receiving 40 pounds of phosphorus per acre per year and an unfertilized wooded watershed. The farmed watershed is farmed on a full conservation basis.

Holt et al (29) suggest that the losses of dissolved inorganic phosphorus in the U.S.A. range from 0.03 to 0.8 pounds per acre per year. They quote results by Timmons in Minnesota on Barnes loam, showing NH_4F - extractable phosphorus in sediment loss, ranging from 0.02 pounds per acre per year on a corn-oats-hay rotation to 0.9 pounds on summerfallow.

Campbell and Webber (13) in a study of Canal Lake in Ontario found very small amounts of phosphorus coming from agricultural land, largely in non-intensive grazing. They concluded that most of the phosphorus in this lake was recycled from water vegetation in neighbouring water bodies.

Phosphorus Losses in Seepage, Tile Drains

Although the fixation, adsorption, immobility and unavailability of phosphorus in the soil is well-established, there is potential for considerable movement under some conditions. The amounts are not serious in the economy and efficiency of phosphorus in the soil, but are significant in relation to the generally stated requirements for productivity of water, given other necessary conditions.

Bolton et al (11) showed losses of 0.01 to 0.29 Kg per hectare per year in tile drains on Brookston clay and phosphorus concentrations of 0.15 to 0.27 parts per million. There were rather small differences between fertilized and unfertilized plots. Effluent concentrations of phosphorus were considerably higher in fall and early winter than in late winter and spring.

Carter et al (14), however, found that subsurface drainage to the Snake River had lower contents of phosphorus than the irrigation water applied. The mean $\text{PO}_4\text{-P}$ value for input water was 0.066 p.p.m., the mean value of drainage water was 0.012 p.p.m. Other workers have even concluded that certain surface runoff contains less phosphorus than does precipitation. (Reference as for (8).)

Oglesby (48) states that levels of phosphorus in Green Lake, Washington, causing eutrophic conditions were derived from natural seepage. The situation has been improved through dilution using Seattle water supplies in off-peak periods.

Johnston et al (31) found concentrations of 0.053 to 0.23 p.p.m. phosphorus in tile drainage under irrigation. Losses of phosphorus under four systems ranged from 1 to 17 per cent in drainage effluent plus tail water and from 0.6 to 14 per cent in the drainage effluent. It is noteworthy again that tail water carried less phosphorus than the drainage. The authors state that a maximum loss occurred where there had been extended flooding combined with an application of 84 lbs. per acre nitrogen as ammonium sulphate.

Factors and Possible Factors in Phosphorus Mobility

The fact that ammonium sulphate combined with flooding resulted in higher phosphorus losses in drainage was noted in the study by Johnston et al (31).

Ensminger and Cope (21) noted that the calculated losses of phosphorus, by erosion, were 75 per cent for plots receiving N as ammonium sulphate compared to 32 per cent for plots receiving N as sodium nitrate. This result was obtained on the limed tier of plots in their rotation.

Cooper (15) quotes results by Cole and Gessel on various treatments under Douglas Fir. Table V shows an excerpt of these data.

Table V

Output of Nutrients Beneath Root Zone In
Untreated, Fertilized and Clear-Cut Douglas Fir

<u>Treatment</u>	<u>Nutrient (lbs/acre)</u>	
	<u>N</u>	<u>P</u>
Control	0.48	0.03
Clear Cut	0.87	0.10
Fertilized (200 lb/acre)		
Urea	0.62	0.07
Ammonium Sulfate	0.94	0.15

The soil on this site is a gravelly glacial drift with moderate base-exchange capacity. The increase in the phosphorus movement under ammonium sulfate treatment appears to be quite significant, with other treatments also showing a decrease in retention as well.

In the long term study on clay soils reported by Ridley and Hedlin (51) treatments of 47 lbs N as ammonium sulfate alone and with phosphate and potash were included. Ammonium sulphate alone depressed yields and plots treated with ammonium sulfate showed low phosphorus values and the complete as well as manure treatments showed an indication of greater phosphorus movement into the 6-12 inch layer.

There would appear to be some reason to look at the effect of ammonium sulfate on phosphorus mobility. The results of Ensminger and Cope may have been due to movement below soil layers analyzed, rather than increased erosion. It is difficult to assess any mechanism, but complexing with metal ions, effect of NH_4 fixation on anion exchange characteristics, as well as pH effects and others could be explored.

Dormaar (19) studied electrophoretic characteristics of humic-acid associated phosphorus in Alberta soils. The results showed a rather marked separation of Brown to Thin Black chernozems and Black chernozem to Gray-wooded soils based on electrophoretic mobility patterns. This would indicate ionization and may have pertinence to a difference in mobility of phosphorus in the two groups of soils.

Mack and Barber (37) demonstrated an effect of low incubation temperatures and temperatures during leaching on the amount of phosphorus released when soils were leached by water.

Hunter (30) found that additions of calcium silicate to soil increased uptake of soil phosphorus. He concluded that silicate ion in large amounts probably increased the availability of soil phosphate by anion exchange. There are reasonable indications that active silica has been important in strongly developed soils and could be a factor in phosphorus mobility and losses.

Mobility in coarse textured and organic soils, would, of course, be expected. Larsen (33) recovered 60 per cent of applied phosphorus in leachate from virgin muck soil and 14 per cent from a deep plowed muck. Neller (47) using a very shallow lysimeter showed movement of substantial amounts of phosphorus in an unlimed sandy soil with low pH and moderately low organic matter. Field results showed improved phosphorus retention by liming.

Mulder and Van Veen (44) discuss a number of routes for the effect of micro-organisms on phosphorus by CO_2 formation, organic acids, reducing effect on ferric phosphates, and, in some cases, by production of hydrogen sulfide. It should be noted that the same general scheme could apply to benthic layers in lakes.

Although phosphorus concentrations in the soil solution are generally low there are cases where levels are moderately high. Rhoades and Bernstein (53) surveyed data on soil solution values showing a range of P as PO_4 from 0 to 50 mg. per liter. Just over 73 per cent of values were between 0 and 0.15 mg. per liter, leaving over 25 per cent above 0.15 mg. per liter.

Webber (70) found phosphorus levels in soil percolates of 0.048 to 0.065 p.p.m. with questionable significant difference between high and low fertilizer treatments using liquid poultry manure.

One could conclude that there are conditions which may lead to some considerable mobility of soil phosphorus, including microbiological, chemical and physical conditions. In Saskatchewan, it may be limited and might occur on strongly developed soils under saturated conditions, at contact zones underlain by impermeable layers and, of course, under irrigation.

Potential Phosphorus Losses from Vegetation

Holt et al (29) noted Timmons' data in Minnesota showing almost four times as much dissolved inorganic phosphorus lost from unfertilized hay in a 2-year period as from fallow unfertilized for 6 years and corn receiving 26 lbs of P per acre. Almost all the phosphorus from the hay plots was removed by snow melt water in the spring. Timmons leached samples of frozen alfalfa hay and recovered most of the phosphorus from the samples with 70 per cent in inorganic (orthophosphate) form.

The results reported by Holt et al, raise an interesting question as to potential losses to runoff water from vegetative sources.

Halm et al (26) report that re-cycling of vegetative phosphorus to the soil by microbiological activity is efficient and rather rapid. The study, of course, represents a single limited vegetative regime and is not subject to runoff. Other studies of forested sites conclude that re-cycling is efficient but site vigour as well as other factors appear to have a strong influence.

Potential losses from vegetation would be subject to the same wide range of conditions as holds for soil. Fuller et al (23) show the wide range in phosphorus content and availability to growing plants, for vegetative residues added to the soil. Both factors would have some influence on the potential losses from vegetative residues above or on the soil surface.

Dodds and Warder (18) found that early combining of wheat at high moisture, and drying gave lower phosphorus contents in wheat than maturing and drying in the swath. The result would be a small but significant reduction in the content in straw residues and would probably represent labile phosphorus.

Halstead and Rennie (27) found that soil moisture stress affected phosphorus movement from sources injected in the portion above ground to the root. Environmental conditions will strongly affect the phosphorus content of vegetative tissue. Growth habit and other factors, including fertilizer treatment will have an influence. Perennial species with autumn growth potential, winter cereals, and other species warrant study.

Specific Problems of Frozen Soils, Spring Conditions and the Interfacial Area

The long winters in western Canada are frequently cited, with justification as an ameliorating factor in soil erosion. Reports of phosphorus in runoff (70, 29) under north temperate conditions, and, of course, the nature of runoff in Saskatchewan would indicate that the major loss of phosphorus occurs in the spring.

The effect of temperature as found by Mack and Barber has been mentioned previously. Although Halm et al found efficiency of cycling of phosphorus from vegetative residues, Biederbeck and Campbell (7) have found that simulated fall and spring conditions, freezing, and, more particularly freezing and thawing, will effect drastic reductions in bacteria, fungi and actinomyces. This element may cause wide variations, due to the annual weather variability, in the susceptibility of labile plant-contained phosphorus to losses in snow melt water.

Hinman (28) found a significant though moderate increase in bicarbonate extractable phosphorus after continuous freezing of soil and a further increase with alternate freezing and thawing.

The shallow saturated layer of soil above the frozen soil, during spring thaw has been considered as a potential condition for some denitrification and could also affect phosphorus release through temporary reducing conditions.

Losses from Wooded Areas

Some reference has already been made to wooded sites in relation to other aspects of phosphorus redistribution.

Barton (4) has listed the phosphorus content of drainage from four forested watersheds in northeastern Minnesota as 0.032, 0.060, 0.047, and 0.023 mg. per liter. The influence of legumes is noted for the nitrogen content of these same drainage waters and there appears to be a possible positive correlation with phosphorus content.

Gersper and Holowaychuk (24) report stemflow water with contents of 0.8 to 2.2 mg. per liter of phosphorus, and drip water from the canopy adding 22 pounds per acre per year. It is reasonable to suggest looking at the cyclical behaviour of wooded areas in regard to phosphorus under the climatic and slope conditions in wooded areas of Saskatchewan streams.

Miller (41) has analyzed the cycling of nutrient elements on an ecosystem basis for a slow growth beech forest in New Zealand. The soil is very deficient in phosphorus but the drainage losses of phosphorus still represent 0.2 kg. per hectare per year.

Phosphorus in the Positive - Needs and Benefits

The benefits of phosphorus application to growing crops in North America have been known since the native Indian first showed white settlers the value of placing fish in hills of corn.

Sedimentation is the most universal problem in the universe of water bodies, reservoirs, lakes, harbours, and rivers. Proper fertilization of agricultural and forest crops is one of the positive aspects of erosion control.

Peterson (50) has reviewed the effect of fertilizer use on erosion and runoff. Tables VI and VII contain data for a silt loam soil in Missouri, on which 200 pounds of 0-20-10 per acre on wheat and 200 pounds of 10-20-20 per acre on oats were used.

Table VI

Runoff and Soil Loss From Wheat - 4-Year Average
1943-46

	<u>Unfertilized</u>	<u>Fertilized</u>
Runoff (inches)	9.72	8.15
Soil Loss/Acre (tons)	4.31	2.52
Yield/Acre (bus)	8.4	20.9

Table VII

Runoff and Soil Loss From Oats - 3-Year Average
1947-49

	<u>Unfertilized</u>	<u>Fertilized</u>
Runoff (inches)	2.39	0.24
Soil Loss/Acre (tons)	1.18	0.07
Yield/Acre (bus)	6.6	27.1

It is interesting to note the striking reduction in soil loss from land in oats. Phosphorus contributes strongly during early growth stages providing quicker ground cover in the vulnerable period after seeding. This may well be reflected to a greater extent on the oat crop than on winter wheat.

Stoltenberg and White (63) compared erosion losses, and runoff under two systems of farming. Some of their data is shown in Table VIII.

Table VIII

Measured Erosion Losses and P Content of
Sediment and Water Loss on 4 Crops, Purdue
1947-50

Crop	Farming System	Runoff Inches	Soil Loss Lbs/Ac.Yr.	P*** lbs/acre
Corn	P*	5.11	6300	2.56
Corn	C**	2.25	1490	0.75
Soybeans	P	5.57	8430	3.41
Soybeans	C	3.74	3340	1.72
Wheat	P	2.67	1800	0.73
Wheat	C	1.57	830	0.43
Meadow	P	5.28	190	0.08
Meadow	C	2.84	120	0.06

* Prevailing system
** Conservation system
*** BRAY - P

The conservation system included contour planting and cultivation, barnyard manure, liming, and much higher rates of fertilizer. Phosphate application (P_2O_5) on the conservation system was more than four times that for the prevailing system. The effect in reducing phosphate losses, however, is very marked. It is important to note, however, that the "available" P content of eroded material was increased from 0.093 per cent on the prevailing system to 0.118 per cent on the conservation system.

This latter situation indicates one element in a possible systems approach to runoff and phosphorus. Phosphate application helped to reduce soil losses, total available phosphorus losses, and runoff but the potential concentration of total or dissolved phosphorus in the runoff water was probably increased.

Beddell et al (6) reported earlier data on a similar basis with less instrumentation. One interesting aspect of their data was that there was a progressive reduction in the soil and phosphorus losses for the period 1942-45 after allowing for confounding due to variation in weather patterns. This tends to show a cumulative effect of adequate fertility and management.

The value of phosphorus in its effect on crop quality is pertinent to expressed concerns on nitrate levels in food and feed crops with direct or indirect potential effects on nitrates in the environment.

Baker and Tucker (3) noted that nitrate accumulation in wheat was associated with phosphorus deficiency. $\text{NO}_3\text{-N}$ contents of wheat forage were reduced from 1300 p.p.m. to 300 p.p.m. at early dates of harvest and from 900 to 600 at later dates by application of 15 kg/ha of phosphorus. Higher rates of P had no further effect.

Walsh (68) reports similar effects for phosphorus application on corn where high rates of nitrogen were used. Although yield increases due to phosphorus are a factor, the effect on nitrate content appears to be greater than can be accounted for by dilution on the yield increase.

Doughty and Warder (20), however, demonstrated that phosphorus effects on nitrate accumulation might vary. They found that nitrate accumulation in oats was increased by phosphorus application in tests conducted in the greenhouse. Rates of nitrogen used were moderately high, phosphorus had little effect on yield and the results may be due to a complex of moisture tension, translocation and others.

Lutz et al (35, 36) have found beneficial effects of phosphorus application on the soil per se. They found significant decreases in the modulus of rupture and a significant increase in water retention. They concluded that the change in water retention was due to charge changes on the clays rather than microbiological effects. Both effects could be of some importance, higher water retention could reduce mobility of soluble ions and reduced modulus of rupture could imply some effect on runoff and erosion.

Requirements for other limiting nutrients to enhance uptake of applied phosphorus are important. Olsen and Dreier (49) found small responses to phosphorus applied alone but oat yields were almost doubled and phosphorus uptake increased markedly by application of 40 pounds of nitrogen.

Saskatchewan data on phosphorus responses are extensive. Expected yield increases from application of 15 to 30 lbs. P_2O_5 per acre, based on long term data, on deficient soils, represent potential increased removal of nitrogen on summerfallow crops. Summerfallow represents a marked accumulation of nitrate nitrogen which is not used efficiently on phosphorus deficient soils.

The strong effect of phosphorus in the early stages of crop growth, represents enhanced earlier protection against erosion during the period of highest average rainfall. Cereal yield increases represent straw yield increases of 300 to 1000 lbs. per acre. The heavier residues constitute a major input for control of erosion on summerfallow.

The Sediment Problem and Phosphorus

Phosphorus in combined or adsorbed form represents generally the major proportion of phosphorus lost from the land by surface runoff.

Latterell et al (34) have discussed some aspects of sediment. There is a wide variation in the proportions of organic and inorganic phosphorus in sediments. Equilibrium solutions also showed a wide range in organic phosphorus as a percentage of total solution phosphorus. They note that sediment has a considerable potential to remove orthophosphate from surface waters and suggest that the reservoir of phosphorus in sediment will probably supply phosphorus to the water only to water of low phosphorus concentrations.

Robinson (52) has briefly reviewed the characteristics of sediment and its problems. He notes that phosphorus deficient soil at a sediment concentration of 10,000 p.p.m. could reduce the phosphorus concentration of sewage effluent from 6.6 to 4.3 p.p.m. On the other hand a soil with low organic matter and high clay at a high concentration of 60,000 p.p.m. depleted dissolved oxygen from 8 to 4 p.p.m. in a period of 40 hours.

Rodhe (71) quotes from Mortimer on the effect of redox conditions at the mud-water interface on phosphorus release from the mud or the reverse. The potential effect of sediment on oxygen depletion, therefore, suggests that sediment and the phosphorus in sediment represents a complex system.

The brief comments on sediment would imply necessary liaison between limnologists and runoff chemists or soil scientists, in order to develop a picture of soil and land characteristics and effect on sediment in relation to the effect on receiving water.

Livestock Wastes and Sewage Effluent

In the disposal of livestock wastes in particular, there is probably too much preoccupation with the use of nitrogen rates as the main criterion for safe rates of application to land. N:P ratios in manure are in the order of 3.6:1 compared to as high as 5.7:1 for estimates in grass production. Very high rates of application based on nitrogen balance only, could result in eventual high levels of phosphorus in the soil. The result could be an effect on minor elements such as zinc, potential erosion losses of high phosphorus status soils with changes in land use, and possibly others. There is a need, therefore, to consider crop species, phosphorus and, of course, potassium in the use of high rates of livestock manures.

Martin (38) has stressed the need for adequate soil evaluations to assess and allocate soil areas as a medium for animal waste disposal.

Bouwer (12) discusses the return of waste to the land with an extensive bibliography. Bouwer quotes some data from the Flushing Meadows Project in Arizona. Renovated water in 30-foot observation wells showed concentrations of P at 5 p.p.m. compared to 20 p.p.m. in the effluent applied. It is interesting that the application schedule had a major effect on nitrogen but any effect on phosphorus was not noted. The surface soil in this project is fine loamy sand underlain by a succession of sand and gravel layers. The phosphorus data would suggest the need for care in location of such projects in relation to possible seepage, even in regard to phosphorus.

Wooded areas are also being used for effluent disposal. There has been enough work done on forest land management to suggest that management to maintain a vigorous stand is essential. Studies of wooded sites (15) show that nutrient retention is severely reduced in unproductive stands. One might even surmise that emergent pest control could be a factor in maintaining a productive stand.

Surface application of animal wastes on steep slopes and frozen soils must be considered as a potential source of significant nutrient losses. Although studies in Wisconsin (8) indicate that livestock manures are major sources of nutrients to lakes, other studies indicate that surface application due to the effect on infiltration, may give results which do not support any universal prohibition of surface application.

A study by Meiman and Kunkle (40) indicates that water quality as affected by irrigation and grazing is best assessed by bacterial monitoring rather than turbidity. Nutrient content was not analyzed but would probably parallel the turbidity to some degree at least. Animal grazing may serve to contribute more to water quality problems through bacteria and growth factors than by nutrient outgo from grazing land.

Phosphorus Technology and Application

Methods, times and other factors in application are important both for efficient crop utilization and preventing losses from the land.

Methods and times of application for perennial crops are particularly important. Rogers (55) using simulated rainfall at high intensities of 3.0 to 3.75 inches per hour, found losses of surface applied phosphorus in the average range of 12 - 13 per cent of that applied with a minimum of 2.7 per cent and a maximum of 22 per cent. He worked on slopes from 12 to 40 per cent and noted the highest losses from the 12 per cent slope, on a silt loam soil. This result would suggest that solution of phosphorus by runoff water may show a complex relation with the pattern of water movement. Munro's data (45) on water extractable phosphorus indicates that soil chemistry as well as shaking time is a factor and this could be reflected in some degree by field conditions.

Siemens et al (57) showed the effect of tillage on phosphorus soil test values, Table IX, after broadcast application of phosphorus.

Table IX

Tillage Treatment	Soil Test Values for P lbs/acre		
	0-3 inches	3-6 inches	6-9 inches
Disc, plow, cultivate, harrow	58.2	58.8	42.9
Disc, chisel, cultivate	104.0	52.2	37.8
Disc twice, harrow-till	59.7	36.2	31.3
Rotary-Till	70.2	50.2	29.5
Chop stalks till	71.7	37.5	29.5

The effect on distribution of soil test phosphorus is quite pronounced. We have had limited soil tests on smaller depth increments in Saskatchewan which would indicate similar differences for soil test phosphorus, without the effect of added phosphorus.

Table X from Timmons (29) shows that the method of application and incorporation can have a strong influence on phosphorus losses.

Table X

<u>Fertilizer Application</u>	<u>P lost in Water runoff as PO_4, p.p.m.</u>
Check	0.08
Broadcast, plowed under	0.09
Broadcast, disced in	0.16
Broadcast, no incorporation	0.30

Data from Saskatchewan (62, 66, 72) on soil test values after long term additions of phosphorus as compared to heavier similar additions as one application, to study residual benefits, shows two effects. Residual yield increases from high rates are similar for some period, to that from annual application of moderate rates. Extractable phosphorus values are much higher for the high rates of application for an extended period. Even if infrequent heavy applications were found to be economically feasible the effect on potential erosion losses would have to be considered.

Methods, rates and times of application and further study of phosphorus technology to increase availability of applied P, are all areas warranting emphasis. Application times for perennial crops, in relation to soil conditions and peak runoff potential periods, need particular attention.

Phosphorus, General

The phosphorus content of precipitation has received some attention. The wide variation in levels in rainfall (15, 29) suggest effects of industry, burning of vegetation and agricultural practices. The condition of phosphorus returned in rainfall during or shortly after a dust storm would be useful. One might wonder about the chemistry and solution of phosphorus adsorbed on minute soil particles serving as nuclei of large rain-drops.

The sediment contributions and its characteristics, for that portion coming from stream-bank, road ditch and other similar point sources, requires study. Allocation of the total sediment or phosphorus load of a stream to the acreage of the drainage basin on a tons and pounds per acre basis is meaningless.

The particular requirements and conditions of Saskatchewan and western Canada generally merit careful study as to water quality control and research. Yield of water for surface storage is a regional requirement that must be integrated with erosion control and efficient use of water. Cultural methods to increase water yield on the Eastern Rockies have been studied and our current concern with water quality would require that this aspect be added to water yield studies.

A number of hydrologic facets are important in the study of nutrient losses by surface runoff. The runoff coefficient varies from 10 acre feet per year per square mile in southwestern Saskatchewan to 300 acre feet or more in local areas of the northeast. Chinook conditions are common mainly to the southwest.

Stream gradients, land form and other factors can result in sediment deposition or removal under varying runoff volumes.

Snow pack characteristics warrant study. The snow pack from summerfallow fields frequently contains considerable drift soil. Although Moss (73) found little enrichment in phosphorus average, some locations showed higher levels of phosphorus in drifted material. The snow pack as affected by shelterbelts, snow fencing, and other obstructions can aggravate erosion as well as improve water yield for reservoirs.

Summary and Conclusions

The one very obvious and definite trend in phosphorus distribution and redistribution in the environment is that due to the impact of concentration through urbanization, industrialization and intensive livestock operations.

Historically there have been major effects of fauna, flora and physico-chemical characteristics on phosphorus redistribution.

Much of the research work and estimates of phosphorus losses in this paper are from U.S.A. research. In spite of some shortcomings in earlier data, a case could be made for an apparent decline in phosphorus losses from cropland over time, while use of phosphorus fertilizer increased markedly. The emphasis on soil conservation, with adequate fertility as a major facet, has probably been a major factor, if the above is true.

As a follow-up, it might be recommended that renewed emphasis on land use and conservation is a major requirement. There is little doubt that the major output from agricultural land in general is that due to soil erosion. Cropland in Saskatchewan increased from some 35 million acres in the early 1940's to over 46 million acres in 1970. Summerfallow acreage increased from 11 to 13 million acres generally in 1940-49 to over 18 million acres in 1969. A consideration of Toogood's data (65) would indicate that any change in sediment and total phosphorus would correlate more closely with this change in land use than with the erratic and moderate use of phosphate fertilizers.

Fruh (1) makes one or two interesting statements viz "One cannot state a priori what the limiting nutrients in any lake or reservoir are", and, further, "In particular, the current mental stagnation of the sanitary engineering field about the super importance of P should be broken".

We can only surmise the thinking behind Fruh's statement. It can be suggested, however, that he is concerned that only P and N have received major attention, that eutrophic conditions do not always correlate with P, N, or P and N concentrations. Fruh emphasizes the extreme importance of research, including satisfactory quantitative evaluation techniques for the evaluation of the bacteria link in eutrophication. He insists that this is the area where research is needed to solve eutrophication problems.

It would not be difficult to find an echo of Fruh's statements in soil science but some progress has been made.

It would be wrong to quote Fruh out of context. Regardless of information gaps, phosphorus is an important limiting element for production in water as it is on land. Conservation of phosphorus supplies alone, warrants research to establish feasible economic methods for re-cycling, more efficient use and methods of application of phosphorus used as fertilizer, and a renewed emphasis on land use and conservation.

There could be obvious benefits in greater liaison between soil scientists, limnologists and other personnel involved in water management and research. Conservation must always include water as well as land

The whole area of land and water management, appears to be one in which a systems approach should be considered. Many water basins represent a complex of land forms, land uses, streams of varying age, character and complexity. Only by studying the segments individually and co-ordinating the results on an integral basis will meaningful results be achieved.

There is a large amount of research data available on a world basis but extrapolation of data is problematical and fraught with potential errors. For Saskatchewan, research and management programs must zero in on the specific environmental characteristics which must be assessed. We have tried to outline in some fragmentary fashion the universe in which analysis of phosphorus in the environment may be studied. Only by more detailed analysis could the structure of an adequate research and development program be evolved.

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